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REPORT

'CARFAX': the effects of co-channel interference

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THE BRITISH BROADCASTING CORPORATION

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"CARFAX" : THE EFFECTS OF CO–CHANNEL INTERFERENCE

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Summary

The Report describes subjective tests performed to ascertain the level of co-channel interference that would be tolerable during the reception of a "CARFAX" announcement, due to other distant "CARFAX" transmissions occuring simultaneously.

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"CARFAX" : THE EFFECTS OF CO-CHANNEL INTERFERENCE

M.E. Bailey, B.A.

1. Introduction

"CARFAX", the traffic information service proposed by the BBC, uses a dedicated network of low-power, medium-frequency transmitting stations distributed over the U.K., all operating on a common carrier frequency and on a time-sharing basis such that nearby stations never radiate simultaneously.[1,2] The minimum distance between the "CARFAX" stations that are permitted to radiate simultaneously depends on the degree of co-channel interference (c.c.i.) that can be tolerated. Early work[3] has suggested that a protection ratio of 18 dB is adequate, but this assumes that the interfering signal is due to only one predominant co-channel source which is amplitude-modulated by a speech signal similar to that used for "CARFAX" messages.

In practice, however, it is likely that several interfering signals of comparable strength will be present, particularly if other countries were also to adopt "CARFAX" using the same carrier frequency. The interference may generally be expected to be caused by the amplitude-modulation of the remote "CARFAX" transmitters but it may occasionally be due to the f.m. coded START or FINISH signals which are radiated before and after each message.[1,2]

This Report describes subjective tests performed to obtain further information concerning co-channel interference in "CARFAX" and, in particular, to obtain protection ratios for the practical cases in which more than one interfering signal exists or in which an occasional interfering START or FINISH signal can be heard. The term "protection ratio" is assumed in this report to be the margin by which the wanted field-strength must (in planning the service) exceed the sum of the powers of the interfering field strengths considered, in any part of wanted service area. The term "interference ratio" is used to denote the ratio by which the wanted field-strength exceeds the sum of the powers of the interfering field strengths considered, at a given geographical location.

It is assumed that the channel is dedicated to "CARFAX". Thus, the effects of co-channel interference from sources other than "CARFAX" transmitters are not considered. The effects of adjacent channel interference are similarly not considered, although it is assumed that this form of interference is less troublesome in "CARFAX" than in conventional m.f. reception, because of the smaller bandwidth occupied by "CARFAX".

2. Contributions to the interference

The co-channel interfering signal of interest is the sum of the signal contributions from all the other "CARFAX" stations which are transmitting simultaneously. The interference can arrive both by direct ground-wave propagation and by sky-wave reflection from the ionosphere. The process is illustrated in Figure 1 which shows a single, remote, interfering transmitter during the period when it radiates a START signal; the transmitters immediately surrounding it radiate inhibiting "ring" signals for the duration of the START signal, to limit its reception service-area in accordance with the "ring system".[1,4]

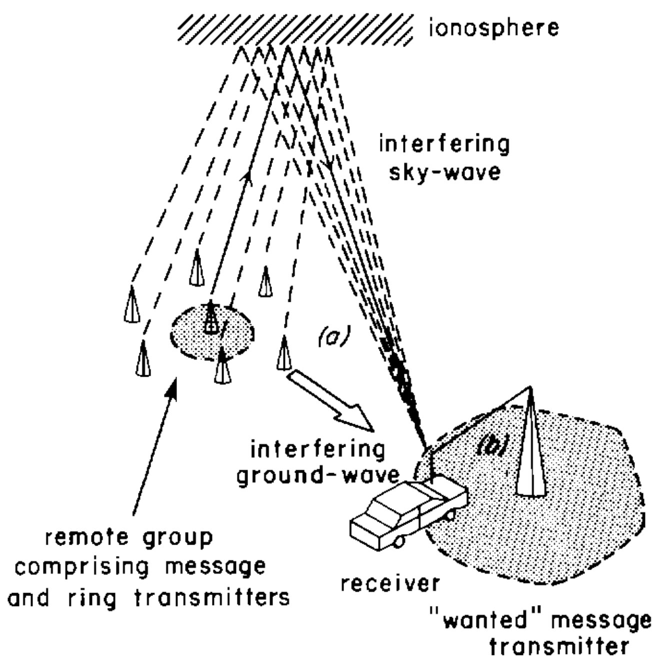

Fig. 1 - Contributions to the interference

——— sky-wave path from interfering message transmitter
- - - - sky-wave path from interfering ring transmitters
service areas of message transmitters

The interference will generally have the greatest effect at the edge of the wanted station's service area, where the wanted field-strength will be least. The interference will increase at night-time and in winter due to sky-wave propagation. Calculations have been made[5] to quantify the amount of interference that would be experienced for a regular, near-infinite lattice of "CARFAX"

transmitters, of which a uniformly distributed proportion radiates simultaneously, as approximately illustrated in Figure 2. For average ground conductivity, only the nearest circle of six interfering stations would contribute significantly to the interference, whilst at night the interfering signals from the nearest eighteen are comparable, and those from further stations are not insignificant.

3. Manifestations of the interference

Co-channel interference in "CARFAX" will have a variety of effects. Firstly, the interference may be audible, although only for the duration of messages received, because the receiver is automatically de-activated outside these periods. A single, interfering, speech-modulated transmission

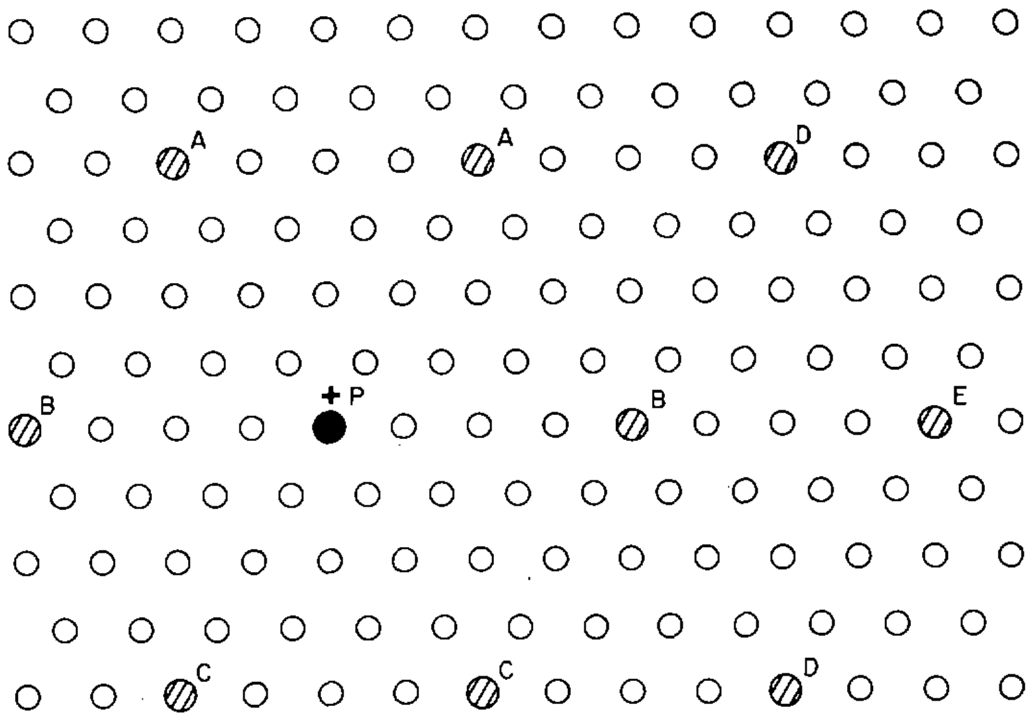

Fig. 2 - Idealised near-infinite lattice of "CARFAX" transmitters, with one in every sixteen radiating messages.

quiescent transmitter.

transmitter radiating wanted message.

transmitter radiating interfering message.

will thus be heard as a voice in the background of a wanted message transmission. In addition to this "voice-breakthrough", a pulsation will be heard due to the carrier beat between the wanted and interfering transmissions. Moreover, if the level of the interference is excessive, overmodulation distortion can occur due to partial cancellation of the wanted carrier by the interfering carrier. This latter effect can be avoided if coherent (synchronous) demodulation is used in the receiver.

Brief bursts of audible interference can also be caused when distant "CARFAX" stations radiate START and FINISH f.m. coded signals. These signals become audible because of f.m. to a.m. conversion which takes place in the presence of one or more interfering, co-channel carriers, as illustrated by the vector diagram Figure 3. The depth of amplitude-modulation generated clearly depends on the relative level of the interfering carrier, but is independant of the f.m. modulation index providing the latter is great enough to cause at

The rest of this Report assumes a regular lattice arrangement of transmitters for convenience. In practice a "CARFAX" system would not be rigidly tied to this arrangement, and in particular some areas might be covered by a greater density of transmitters than others to correspond with variations in traffic density. However, the average power radiated per unit area would remain approximately a constant, because transitters serving smaller areas would have to radiate less power than those serving larger areas in order to achieve equal field-strengths at the service-area boundaries, an essential requirement for the "ring"system.

For a typical edge-of-service-area reception point P (Figure 2), the relative levels of r.f. signals from the nearest eighteen interfering stations are as listed in Table 1 for night-time propagation and a homogenous ground conductivity of 10 mS/m*. (Median night-time sky-wave figures are assumed.)

*Calculations by P. Knight.

TABLE 1

Relative weightings of eighteen interfering signals at night-time

Station (Fig. 2)	Number of Stations	Relative level received at P (due to each station)
A	2	0 dB
B	2	−2.0 dB
C	2	−3.1 dB
D	6	−5.9 dB
E	6	−7.0 dB

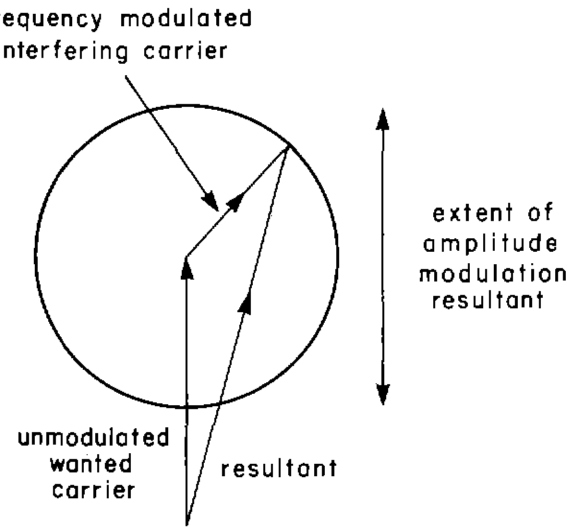

Fig. 3 - Vector diagrams illustrating f.m. to a.m. conversion in the presence of co-channel interference.

least one complete revolution of the interfering carrier phase. The resultant a.m. interference contains frequencies related more to the peak deviation than to the modulation frequency of the f.m. signal, and this can sometimes make the f.m. coded signals, with their peak deviation of ± 2 kHz, particularly objectionable.

A second mechanism whereby the interference can theoretically be manifested is found in the f.m. coded signal decoder in the receiver. A sufficiently high level of interference will inhibit reliable reception of START and FINISH signals and could cause false triggering of the receiver. However, because f.m. coded signals of high modulation-index are used and an f.m. demodulator is employed in the receiver, capture effect operates and ensures that, unless the level of the interfering signal is virtually equal to or greater than the level of the wanted signal, the coded signals will be received correctly. It is, in fact, this mechanism which ensures that messages from only the transmitter with the more strongly received level are heard by the motorist.[1,4] At such levels of interfering signal, the audible interference caused would always be quite unacceptable, so it is the audibility which determines the protection ratio required. For this reason the rest of this Report deals only with audible interference.

4. Experimental difficulties encountered

The assessment of co-channel interference for "CARFAX" presents a number of difficulties not encountered in conventional radio planning. Not only are there the effects of multiple interfering sources and of occasional f.m. coded signals, but there are also the psychological aspects connected with the change over from silence (or the motorist's normal listening) to the "CARFAX" announcements. Motorists might, for example, be prepared to tolerate different standards for "CARFAX" in view of the fact that any interference present will be audible only for the duration of the messages. Moreover, the presence of car noise may have a significant effect on the annoyance caused by the interference.

In order to take account of these effects, "CARFAX" with co-channel interference was simulated in the laboratory, as it might be received by the road user, and the candidates of subjective tests were first briefed as to the nature of the proposed service before being asked to assess the subjective impairment caused by the interference. Various levels of interference were simulated, using various numbers of interfering signal sources all modulated according to the experimental transmission specification of "CARFAX" (reproduced, in brief, in the Appendix).

The subjective tests were carried out in two parts. In the first part, preliminary tests were made in which only interfering message-modulated interfering source was used. In the main tests, up

to eighteen message-modulated interfering sources were used.

5. Preliminary tests

The preliminary tests assumed that only one interfering signal would be dominant, as might be the case in day-time reception or when the service was not at peak demand.

The object of the tests was to obtain subjective assessment figures for various levels of message modulated (a.m.) interference, and for the relative annoyance of interfering START or FINISH signals, with or without the ring signals, associated with each interfering message transmitter[1] and to assess the effect of lengthening the interfering f.m. coded signals or increasing their regularity.

5.1. Experimental equipment

The equipment used to simulate the wanted and interfering "CARFAX" transmissions is shown in block form in Figure 4. Each r.f. "CARFAX" signals. The message modulation of both wanted and interfering stations was pre-emphasised and compressed as indicated.

The powers of the ring transmitters were set to 6 dB below the power of the message transmitter, since it was thought that this would be required of transmitters in the ring mode in order to give a service area overlap[4]. Since the receiver would be relatively distant both from the message and the ring transmitters in the interfering group the received levels would also be in this ratio, approximately. The relative c.c.i. level was then defined as the ratio of wanted to interfering "message" transmitter powers as defined by the attenuator shown in Figure 4.

A prototype "CARFAX" receiver[6] was used. This was of the straight-tuned radio-frequency kind with envelope detection for the a.m. message, and de-emphasis to match the transmitted pre-emphasis. Its performance was thought to be typical of future "CARFAX" receivers.

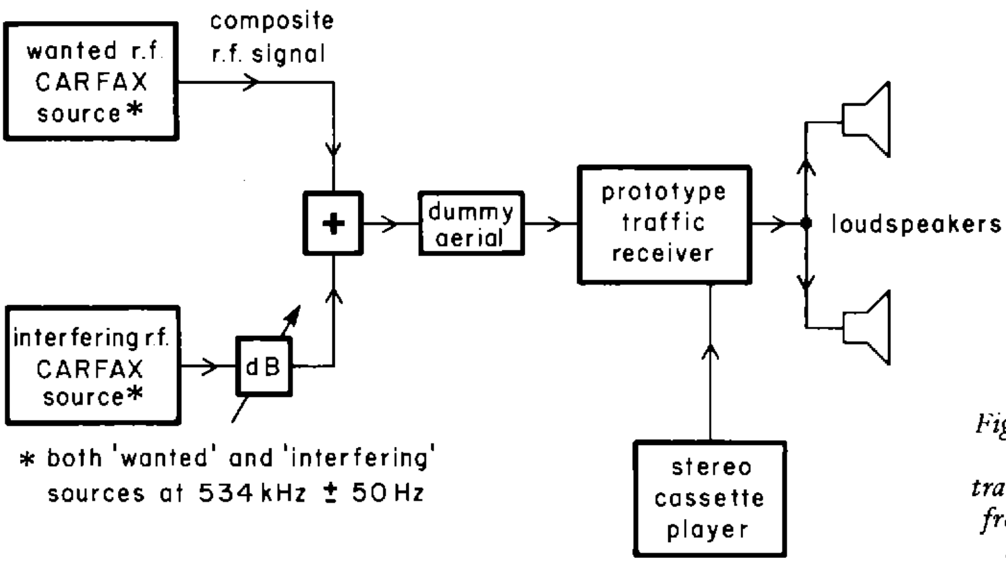

Fig. 4 - Apparatus to simulate reception of a wanted transmission with interference from one distant transmitter and its ring transmitters.

source is shown in greater detail in Figure 5; a number of signal-generators was used to simulate the operation of the transmitter radiating a message and its ring transmitters, and the sequence of events required for a "CARFAX" transmission which is shown in Figure 6, was governed by a tape recording.

The transmission parameters used are as defined in the Appendix except that, in these preliminary tests, a burst length of 0.5 s was used for both the START and the FINISH f.m. coded

5.2. Programme material

The programme material chosen for the tests consisted of spoken announcements of traffic information preceded and terminated by jingles (see Figure 6). It was arranged so that the output of a stereo music cassette-player as heard before and after messages to represent normal in-car listening, and the switch over from this to the "CARFAX" message was performed automatically on receipt of the (wanted) START signal, and back again on receipt of the FINISH signal, in

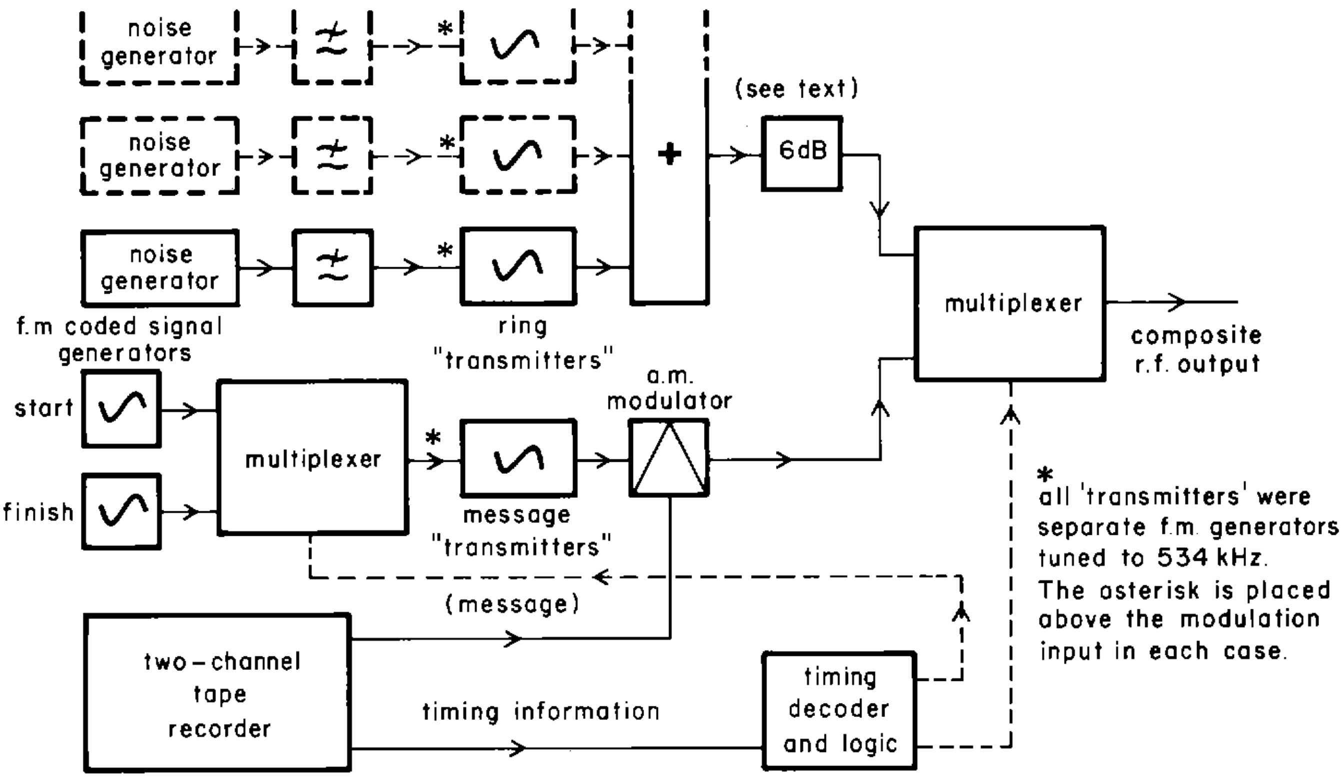

Fig. 5 - A "CARFAX" r.f. signal source showing message and ring generators.

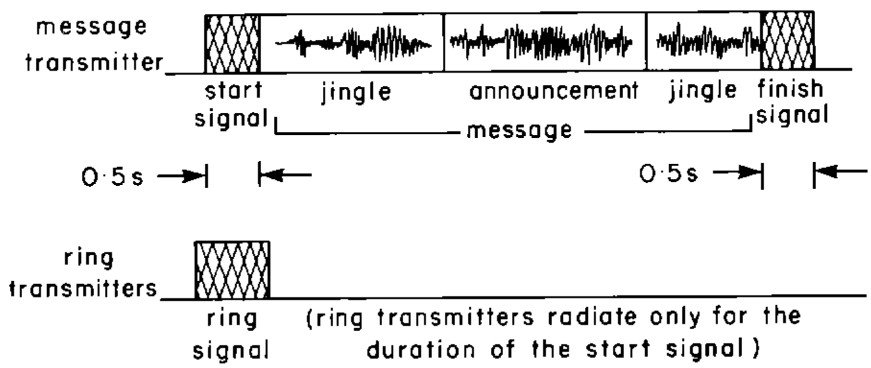

Fig. 6 - The time sequence for the "CARFAX" message transmission use in phase one.

accordance with the normal operation of "CARFAX" receiver.[6,7] The programme material was arranged so that gaps between either the music and the jingle, or the jingle and the spoken traffic announcement, were minimised.

5.3. The number of interfering ring signals

A pilot test showed that the audible interference caused by a START signal together with one "ring" signal, was virtually indistinguishable from one with several "ring" signals transmissions. For this reason only one "ring" transmitter was used in the actual tests.

5.4. Briefing and format of the tests

The nature of "CARFAX" was explained to the candidates, who were all engineers. It was made clear that a future service would be intended to provide an information channel rather than an entertainment channel, and certain "administrative noises" such as the interference due to distant START signal transmissions might be inevitable.

Each test consisted of a "CARFAX" message transmission which interrupted the output of the music cassette player. Interference was added in such a way that both interfering speech modulation (a.m.) and one or more f.m. coded signals were present. The candidates were asked to grade the annoyance caused by these two effects separately for each test, using the CCIR 5-point impairment scale reproduced below.

TABLE 2

CCIR Impairment scale

Grade	Impairment
5	Imperceptible
4	Perceptible but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

5.5. Results

Twenty-five candidates assessed the tests. The average grading for "message" and "f.m. coded signal" interference for each test is plotted against the relative wanted to c.c.i. level, in Figure 7. For all of the results plotted, two interfering f.m. coded signals occurred during the reception of the wanted message.

Results not shown in Figure 7 indicated that the annoyance caused by START and FINISH signals of equal duration was approximately equal, irrespective of whether ring signals were present and for this reason only START signals are considered in the rest of the Report. The annoyance caused by hearing two such signals during a wanted message was graded one half-grade worse than if only one was heard with the same level of interference. Finally, it was found that the effect of extending the duration of the f.m. coded signals from 0.5 s to 1.5 s was to increase the impairment by about one half grade. As will be seen from Figure 7, this corresponds to a 4.5 dB change in c.c.i. level.

6. Main tests

In the main tests, the interference was considered to be made up of one or more "CARFAX" transmissions of comparable strength. Multiple interference of this kind will be more common than that of a single interfering source, especially at night with sky-wave propagation. Even in the day-time, interference from about six distant stations could well be of significant level, as discussed in Section 2.

Both speech and f.m. coded signal modulations were applied to the interfering transmissions, as in the preliminary tests. In addition, reception using a synchronous rather than an envelope message-signal demodulator was investigated to see what subjective advantage could be gained from the removal of overmodulation distortion.

6.1. Experimental equipment

Various attempts were made to simulate the night-time case of many interfering "CARFAX" transmissions of comparable strength. To start with, simulated "CARFAX" messages were combined at baseband by multiple audio dubbings using a tape recorder. This work demonstrated that the subjective annoyance of many interfering speech signals was less than that from a single interfering source of the same relative power as the composite interfering signal.

Combining and adding the interfering signals at baseband unfortunately does not take account of such effects as carrier phase and frequency differences or overmodulation distortion, as outlines in Section 3. A test was therefore performed in which six speech-modulated r.f. interfering sources were added to a wanted r.f. "CARFAX" source. The results of this test were sufficiently different from those obtained by combination at baseband to warrant using true r.f. sources. The decision was therefore made to construct a unit containing eighteen independant amplitude-modulated carrier generators as shown in Figure 8. The number eighteen was chosen rather arbitrarily but is the number of transmissions with comparable signal levels that would be received at night-time, assuming the geometry and transmitter duty-factor of Figure 2. For stability reasons, each generator was based on a crystal-oscillator, and the frequencies of the eighteen oscillators were adjusted to give slow beats between each of them in the range 0.3 to 10 Hz. No two oscillators were allowed to become locked in frequency and phase; thus the relative phases of the sources were effectively random, as they would be in practice, espe-

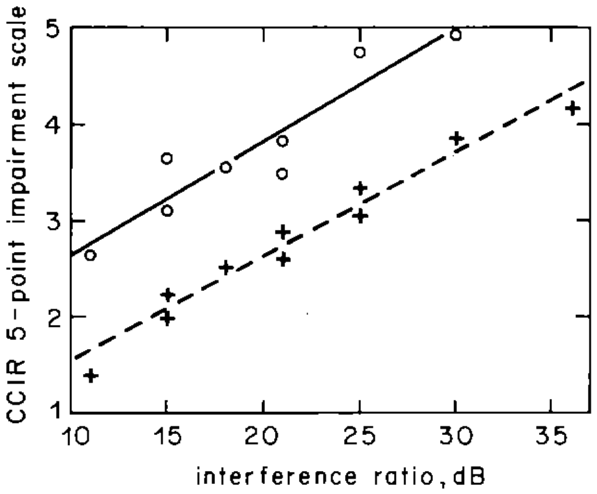

Fig. 7 - Results of preliminary tests.

o average gradings for interference due to message signal

+ average gradings for interference due to two successive f.m. coded signals

—— best fit straight line to message gradings

- - - best fit straight line to f.m. coded signals gradings

cially after an ionospheric reflection.

In practice, each contribution to the interference could suffer sky-wave fading, particularly at night-time. Sky-wave fading can be simulated by increasing the number of r.f. sources used[8]; however, the experimental results show that the subjective impairment caused by the interfering signals (for a given overall interference ratio) decreases assymptotically as the number of sources increases, so that above eighteen sources, little change in subjective effect would be noticed. For this reason, and to simplify the experimental equipment as much as possible, sky-wave fading of each, individual contribution was not deliberately simulated.

The carrier generators were amplitude-modulated by eighteen non-correlated speech signals recorded in three 8-track tape recorders. Each carrier generator was individually adjusted in level to give either equal weightings or the weightings which would occur in practice as listed in Table 1 (see Section 2). The resultant composite

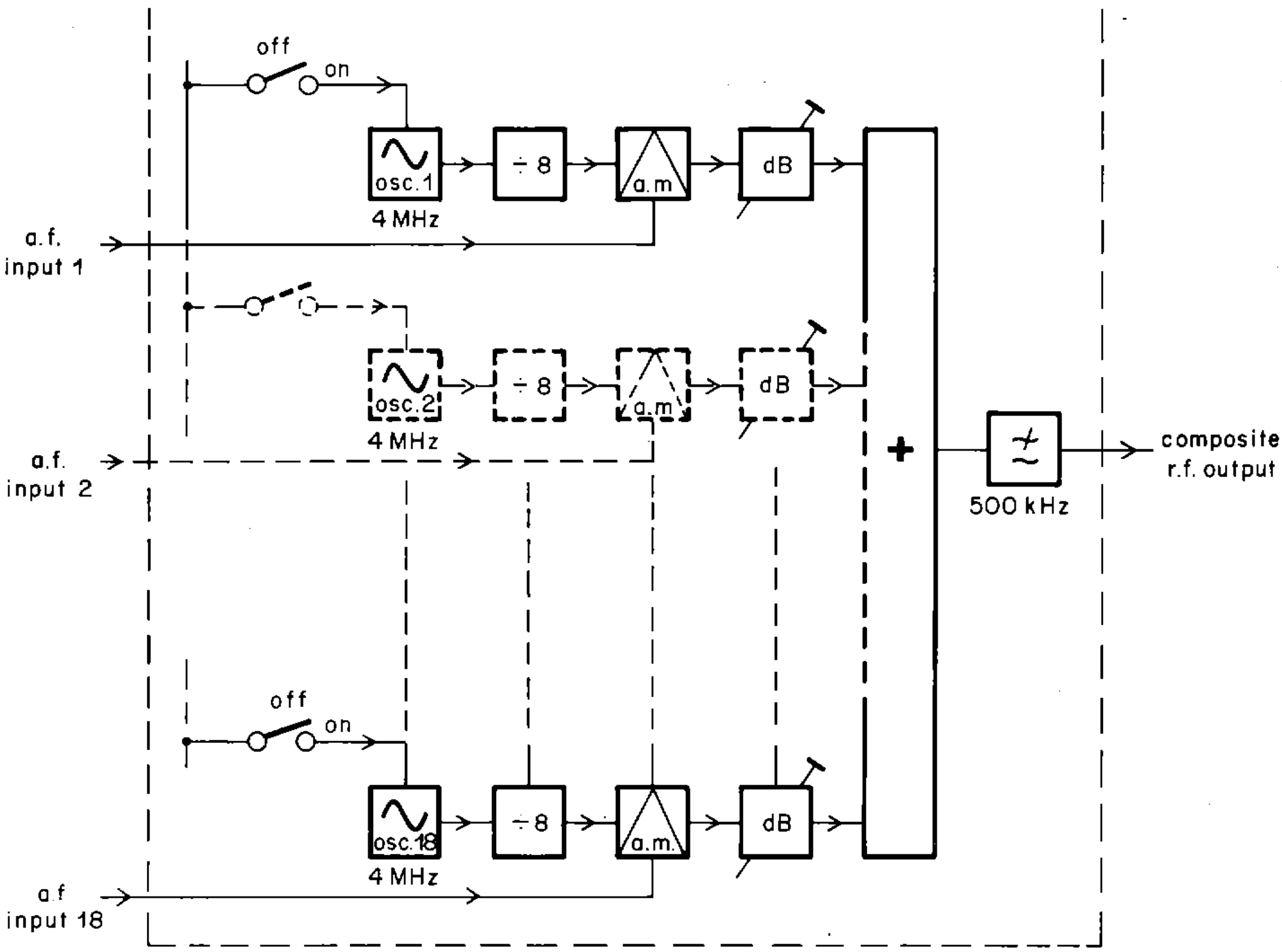

Fig. 8 - Apparatus for generation of a composite interfering signal.

'interfering' signal formed by summing these r.f. signals was added to a simulated 'wanted' "CARFAX" message signal as shown in Figure 9, and fed to a typical receiver. The attenuator 'A' was set so that the r.f. power of the composite interfering signal was equal to that from the wanted source when attenuator 'B' was set to 0 dB. By this means attenuator 'B' was calibrated in terms of the wanted to interfering signal power-ratio directly. Settings for attenuator 'A' (to the nearest 0.5 dB) are shown in Table 3 for the parameters used in the tests.

6.2. Programme material

Each of the eighteen interfering speech signals was made up of traffic information announcements so that the speech modulation was continuous. This represents a worst case, unlike the format used in the preliminary tests, and may in fact be more realistic as the greater proportion of "on-the-air" time would probably be spent in radiating messages.

The format used for the wanted message was slightly different, but again possibly more realistic than before: a single, introductory jingle comprising two bell-like tones was used to precede a traffic announcement. This might be useful for heralding a "CARFAX" message, but left gaps in the wanted modulation through which any interference was heard.

TABLE 3

Attenuator A settings

Number of interfering sources used	Attenuator A setting	
	Equal weighting	Weighting in Table 1
1	0 dB	0 dB
6	8 dB	6 dB
18	12.5 dB	8.5 dB

To test the impairment caused by the f.m. coded signals, one of the eighteen interfering sources was replaced by a signal-generator modulated with the f.m. coded START or FINISH signals, as defined in the Appendix. In these tests, the correct START signal duration of 0.8 s was used, although no ring transmissions were used, their inclusion having been shown to have a negligible effect on the impairments (see Section 5.5).

The receiver used was identical to that used in the preliminary tests (see Section 5.1), except that an optional synchronous demodulator for the message signal was added as shown in Figure 9. In order to reduce the distortions due to over-modulation, the carrier recovery employed in this demodulator must be valid even in the presence of severe co-channel interference, and this would present a design challenge in practice. (Brief laboratory tests have shown that a phase-locked-loop carrier-regenerator which switches to a very long loop time-constant in the presence of over-modulation is viable. However, for the purposes of the tests, an appropriately phased carrier feed was obtained from the wanted source, as shown in Figure 9.)

No normal in-car cassette-music was used in the main tests because experience gained in the preliminary work showed that this neither aided nor detracted from the subjective assessment.

6.3. Car noise

Brief tests were made in which ambient acoustic noise recorded in a car travelling in typical traffic conditions was replayed during the simulation of wanted message and interference. It was clear that the car noise helped to mask the interference, but on the other hand made it harder to understand the sense of the wanted message. Since it was difficult to typify a 'standard' road noise, and since the effect of such noise was simply to detract from the assessment of the interference question, it was decided not to pursue the use of car noise.

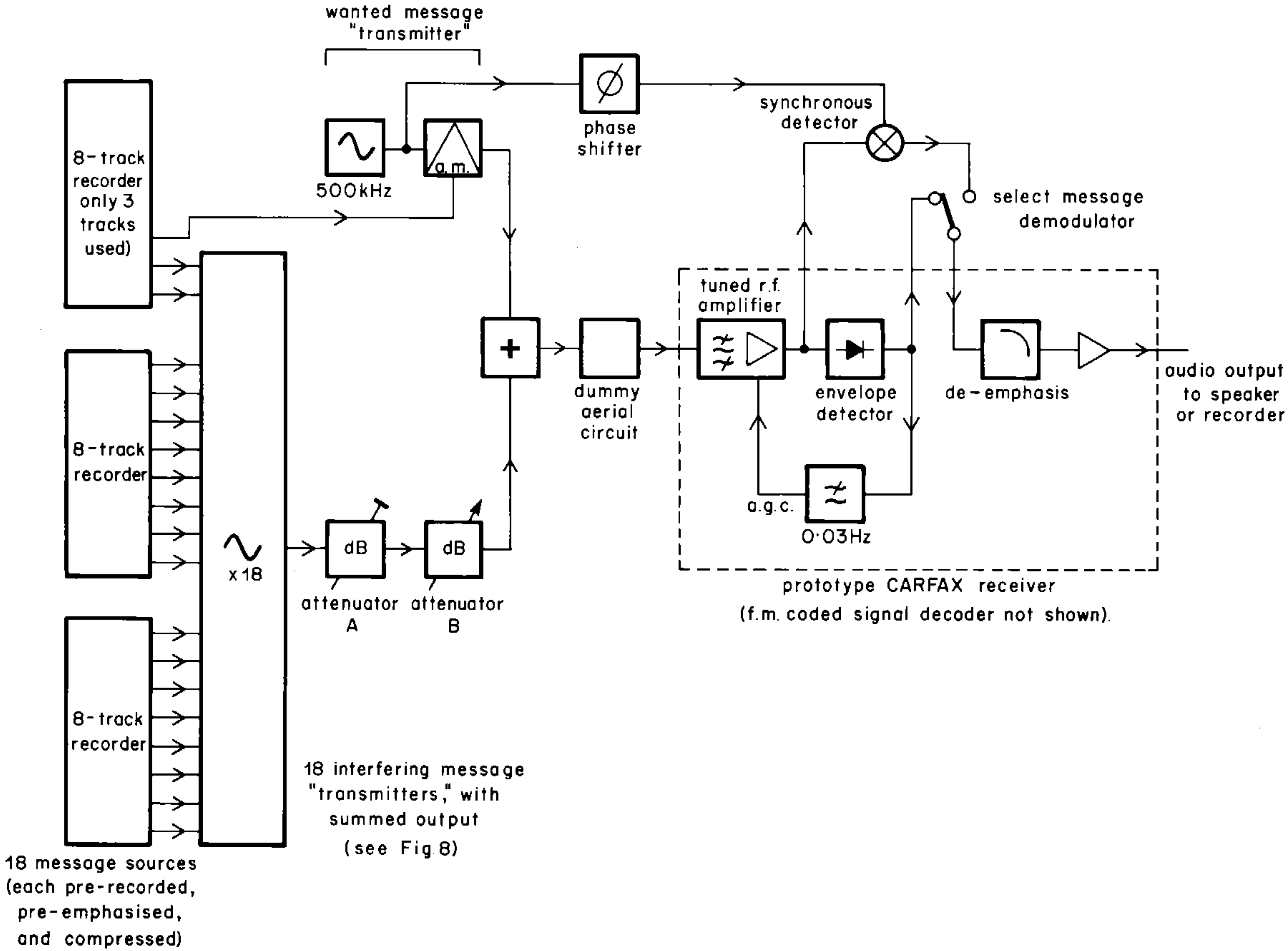

Fig. 9 - Apparatus to simulate reception of the wanted and composite interference "CARFAX" signals.

6.4. Briefing and format on the tests

The candidates were asked to assess the overall impairment caused by the interference, whether carrying only speech modulation or both speech and f.m. coded signals. However, with the object of gaining more understanding of how to judge impairment in a service intended to convey information rather than entertainment, the candidates were asked to grade the effect of the interference in two ways. Firstly they were asked to grade the impairment to reception quality using the 5-point CCIR scale as used in the preliminary tests. Secondly they were asked to grade the ease of intelligibility of the spoken messages as affected by the interference, using the same wording as the CCIR quality scale.* Candidates were asked to try to make allowance for the limitations of enunciation in the test excerpts, as the announcers were not professional speakers. The two grading scales are reproduced below in Table 4.

Results for tests using six or eighteen interfering sources are given in Figure 10, (b) and (c) respectively. In order to compare the three sets of results, Figure 11 shows the previous three figures superimposed with various x-axis offsets such that a single straight line can be fitted to minimise the squares of the deviations of all three sets of results from the line. The x-axis offset required is an indication of the advantage gained by using more sources. This is a rather arbitrary, but nevertheless reproducable method for combining the results and leads to the conclusion that, for a given relative power of composite interfering signal, there is an advantage in subjective annoyance worth about 2½ dB gained by increasing the number of sources from one to six, and a further 2 dB from six to eighteen. It can be seen that the case of intelligibility was assessed on the average one grade better than straight impairment independent of the interference.

TABLE 4

Grading scales used in the main tests

Reception Impairment	Grade	Ease Intelligibility
Imperceptible	5	Excellent
Perceptible but not annoying	4	Good
Slightly annoying	3	Fair
Annoying	2	Poor
Very Annoying	1	Bad

6.5. Results of the main tests

6.5.1. Speech-modulation interference

Forty-one candidates assess the tests, which included excerpts with various relative powers of wanted and composite interfering signals, and composite signals either one, six or eighteen sources. The average gradings obtained are plotted in Figure 10.

Figure 10 (a) shows the results for a single interfering signal, the corresponding results from the preliminary tests are superimposed for comparison. Ideally, one would expect the preliminary results to coincide with the new impairment gradings, but this is not the case. A number of factors may be responsible for this, such as the use of two systems of grading in the main tests which diversifies the assessment and may thus cause the reception impairment to be rated worse that if no intelligibility grading were called for. Secondly, the subjective annoyance caused by the interfering message transmissions could be said to be worse in the main tests because of the longer pauses in the wanted programme material through which any interference was highlighted. Possibly the main reason for the difference is that the interfering speech signal was continuous in the main tests, but of limited length in the preliminary tests. In any case the discrepancy serves to highlight the need to define carefully the condition under which tests such as these are performed. In the following Section recommendations are presented which are based on the worst case - that is the results of the main tests.

* such a scaling is by no means rigorous, and does not necessarily tally with "true" intelligibility measured using word lists, etc.[9,10]

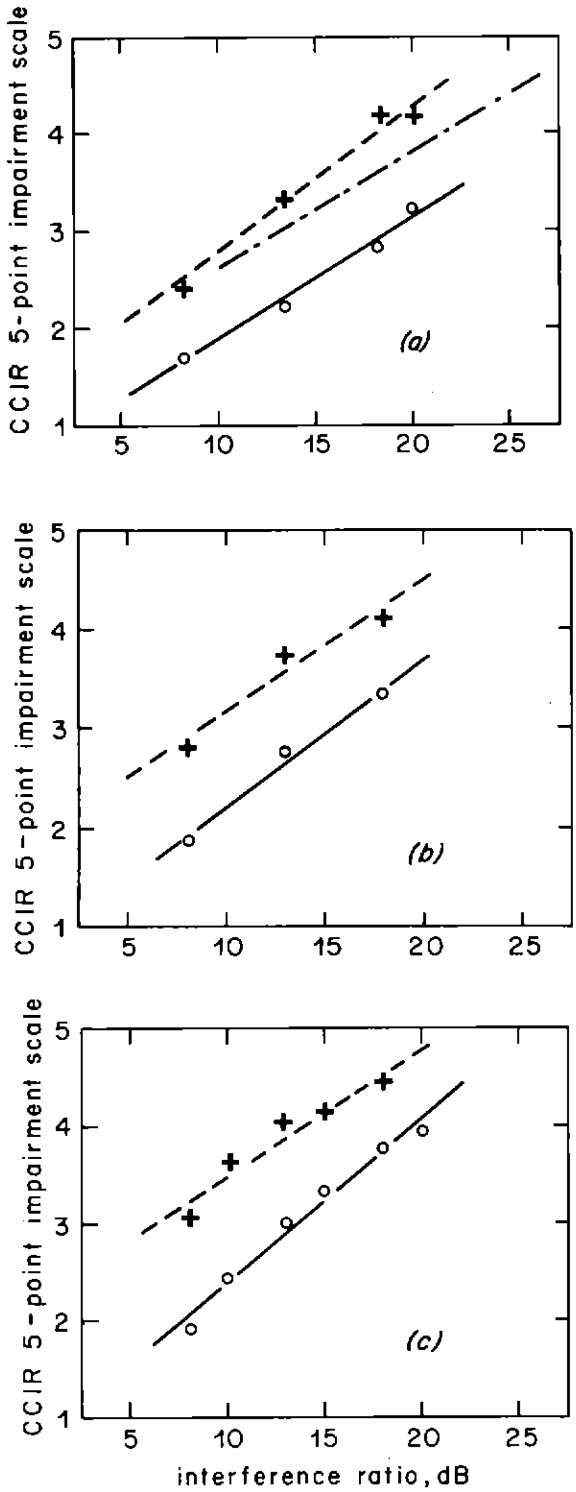

Fig. 10 - Results of the main tests: interfering signal levels weighted as Table 1, envelope message demodulation used in receiver.

impairment scale	intelligibility scale	
o	+	average grading
———	– – – –	best fit straight line

—·—·- results of preliminary (Fig. 7) tests

(a) using one interfering source (b) using six interfering sources (c) using eighteen interfering sources

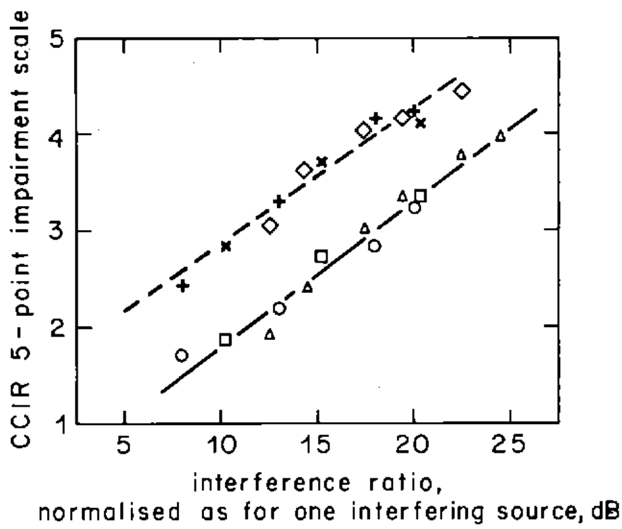

Fig. 11 - Comparison of the results shown in Fig. 10 with the three cases (a), (b) and (c) superimposed with x-axis offsets such as to minimise the overall sum of squares of the deviations from the best fit straight line.

impairment scale	intelligibility scale	
o	+	one interfering source, x-offset of o dB
□	×	six interfering sources, x-offset of 2.4 dB
Δ	◇	eighteen interfering sources, x-offset of 4.5 dB
———	— — —	best fit straight line to above points

Tests were made to compare the effect of the type of level weighting on the annoyance caused by eighteen interfering signals. The average gradings given for an equal level distribution with a 10 dB wanted to interfering power ratio were 2.6 and 3.5 respectively, which differ very little for the corresponding gradings for the weightings given in Table 1 Figure 10, (c) thus showing that within limits the nature of the weighting is not very important to the results.

6.5.2. Interference including START/ FINISH signals

Tests were also made in which one of eighteen interfering signals, each of equal level, was modulated by a sequence of two START signals (see Appendix). The results are plotted in Figure 12 together with the results shown in Figure 10 (c) which are for eighteen interfering signals with no f.m. coded signals added. The relative deviations of the experimental points from the best straight line give no evidence that the

annoyance caused when one of eighteen interfering signals is START tone modulated is any better or worse than that when none of them is START tone modulated.

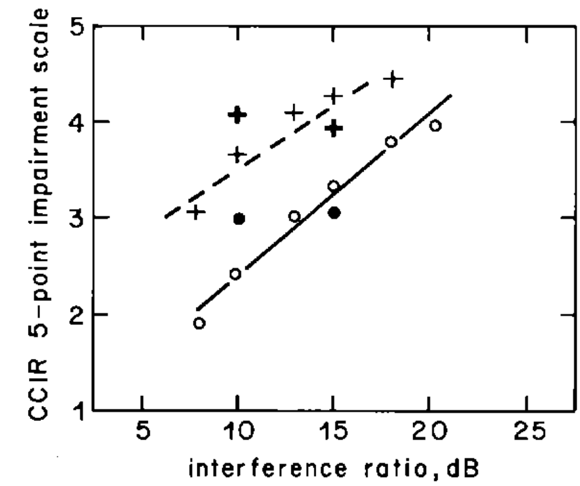

Fig. 12 - Results in which one of eighteen speech modulated interfering signals is replaced by a sequence of two 0.8 s START signals during the reception of the wanted message.

impairment scale	intelligibility scale	
•	✚	average grading for tests with 2 start signals added
o	+	average grading } *
——	— —	best for straight line } *

* for results with no START signals as shown in 10 (c)

This is in contrast to the results of the preliminary tests which showed that START signals carried by a single interfering source are very obstrusive compared with the message modulation.

Figure 13 summarise the relative effects of the various kinds of interfering signal considered so far in this Report. The diagram represents the interference levels required in each case for a given mid-range subjective grading relative to that for a single interfering carrier bearing message modulation only. Thus a single interfering carrier with both START and message modulations ("1S") is shown with a 10 dB higher interference ratio than the similar case with no START modulation ("1M") as using the results shown in Figure 7.

No tests were performed at the time for the case of six interfering signals where one carried START signals. Subsequent tests have, however, demonstrated that the subjective effect of an interfering START signal modulated carrier alone (i.e. message modulation) at a given level is independent of whether other unmodulated carriers are present or if their relative levels providing all interfering carriers are small compared with the wanted carrier. The two broken lines in Figure 13 represent on this basis, the relative overall interference ratios for six and eighteen carriers, where one is START signal modulated and the other unmodulated. The 8 dB and 12½ dB figures are the difference between the overall interference level and the level due to an individual interfering carrier assuming all carriers are of equal level (these figures correspond with those given on Table 3).

Composition of interfering signal shown by:-

M which signifies a message modulated carrier.

S which signifies a START/FINISH modulated carrier.

U which signifies an unmodulated carrier.

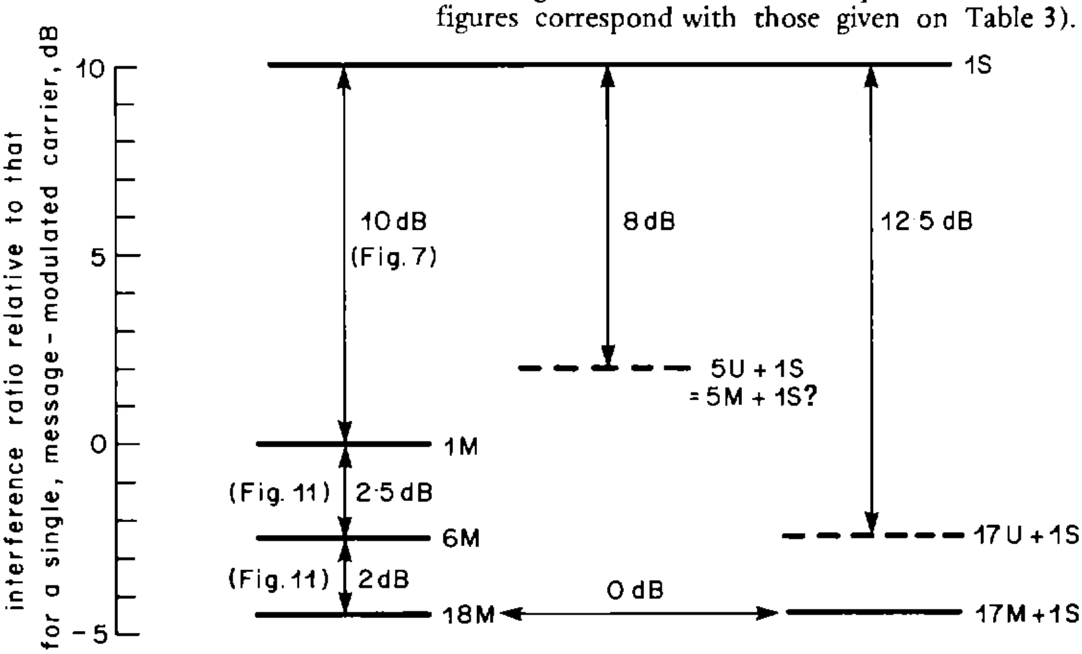

Fig. 13 - Relative interference ratios resulting in a given subjective grading for various interfering signal compositions.

It is clear from Figure 13 that the presence of message modulation on the interfering carriers in the eighteen carrier case must, to some extent, mask the subjective effect of the START signals. It is difficult to predict whether this would happen in the case of six interfering carriers, one START modulated and the other message modulated, hence the question mark against "5M + 1S" in Figure 13.

6.6.3. Other tests

Synchronous demodulation of the message signal avoids overmodulation distortion which can occur in the presence of co-channel interference, and tests were made to compare the subjective annoyance of the interference with synchronous and envelope detectors. The results for synchronous demodulation are shown in Figure 14, where it is apparent that there is no significant advantage in using synchronous demodulation except, possibly, for very high levels of interference. Brief, additional tests showed that the advantage does increase significantly for wanted to interfering power of less than about 5 dB, but such interference levels are unlikely to be experienced in practice.

At the end of each session of test sequences, the candidates were asked what subjective grade should specify the worst co-channel interference allowed in a service such as "CARFAX". The average gradings were 2.5 for reception impairment and 3.1 for ease of intelligibility.

7. Recommendations

Knight and Phillips[5] have shown that for a "CARFAX" network operating over the whole of Western Europe on a single frequency the worst case interference levels would generally be as given in Table 5. This table is quoted directly,* and the "duty factors" of 6% and 4% refer to the simultaneous operation of one transmitter in sixteen and one in twenty five respectively.

*an error in reference 5, whereby this figures were transposed, has been corrected here.

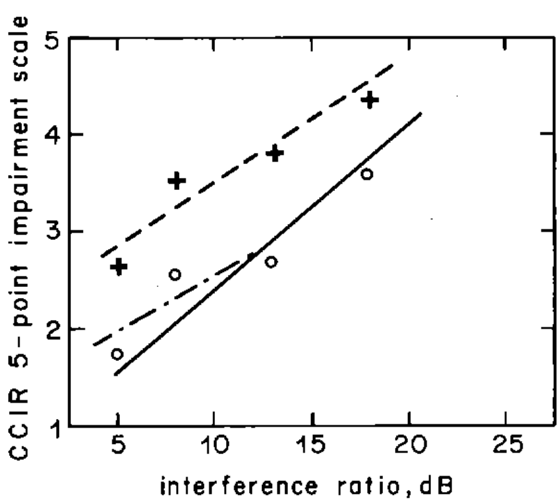

Fig. 14 - Results in which synchronous rather than envelope message demodulation is used in the receiver: eighteen interfering signals are present with the level weighting of Table 1.

impairment scale	intelligibility scale	
o	+	average grading
——	– – –	best fit straight line for results using envelope demodulation, as shown in Fig. 10 (c)
— - —		possible deviation from above line showing advantage of synchronous over envelope message demodulation

TABLE 5

Summary of interference ratios, dB, for a network covering Western Europe, (Values for central part representing the worst case)

Duty factor	Day-time	2 hours after sunset 2 hours before sunrise	Night-time
6% 4%	19 24	16 20	14 17

7.1. Performance with given interference criteria

The worst-case interference ratios quoted in Table 5 can be expressed in terms of the annoyance caused by the interference by reference to the results of the subjective tests described in this Report. Assuming that the "CARFAX" service does extend over Western Europe and is operated with a 6% duty factor, which is itself a worst case, the interference will be made up of about six "CARFAX" signals of comparable strength during the day, or eighteen during the night. (See Section 2.)

The corresponding average gradings when the audible interference does not carry FINISH signals can be read from Figure 11 for six or eighteen sources as appropriate, and these are listed in Table 6. Average gradings are also given for the case in which one of the interfering transmissions carries two START/FINISH signals: these figures are based on Figure 13.

substantially at the same time - in this way receivers would be deactivated when interfering START/FINISH signals occurred and thus no audible interference due to them would be suffered.

7.2. Protection ratios required for a given grading

Alternatively, since it has been shown in Section 6.5.2. that approximately only the individual level of an interfering transmission carrying START/FINISH signals is pertinent to the annoyance it causes, the two types of interference could be segregated and a separate protection ratio enforced for stations radiating START/FINISH signals during a message transmission elsewhere. This suggestion is summarised in Table 7.

In engineering a "CARFAX" system, both the protection ratio for START/FINISH signals and the appropriate one for speech modulated signals would have to be met. Thus, for instance, operation in a regular lattice network covering Western Europe operating with a 6% duty factor,

TABLE 6

Summary of average CCIR gradings for worse case interference ratios suffered in a network covering Western Europe operating with a 6% duty factor (as per Table 5).

Whether interfering START/FINISH signals present	Channel Parameter graded	Day-time (six interfering transmissions)	Night-time (eighteen interfering transmissions)
No	Reception impairment	3.5	3.1
	Ease of intelligibility	4.5	4.1
Yes	Reception impairment	2.8	3.1
	Ease of intelligibility	3.9	4.1

The above grades are thought to be more than adequate for an information service such as "CARFAX", although it may be desirable to guard against the audible effect of interfering START/FINISH signals. The network could be constrained, for instance, so that all transmitters operating simultaneously or those within a certain range of each other indicated START/FINISH signals

in which interfering START/FINISH signals were present would meet the protection ratios quoted in Fig. 5 at night-time, but not quite during the day, for grade 3 or better impairment.

7.3. Use of synchronous demodulator

The use of synchronous message demodulator

TABLE 7

Suggested implementation of the co-channel interference requirements

Field against which protection is required	Number of interfering transmissions	Protection ratio, dB, for grade 3 impairment or grade 4 ease of intelligibility
due to one individual signal which is START/ FINISH modulated	any	28
due to the composite signal of	1	18
number of speech modulated	6	15½
signals	18	13½

in the receiver gives an improvement from the effect of the interference for high levels of interference, although at the levels recommended by Table 7, the improvement is small. Although the f.m. demodulator necessary in the "CARFAX" receiver to detect the START and FINISH f.m. coded signals can, possibly, partially double as a synchronous message (a.m.) demodulator, a very narrow-band carrier filter or its equivalent is essential to effect any improvement over an envelope detector in the reception of the interference-ridden signal, and it is thought that the simple envelope detector would therefore be more practicable.

7.4. Other factors

As additional guidelines, the annoyance caused by the interference is reduced by minimising pauses in the audio programme heard by the motorist. The annoyance may be further reduced in practice by the masking affect of road noise in the car, although this will not apply for listeners using domestic-portable receivers.[4,5]

8. Conclusions

A series of subjective tests have been described, the results of which give information concerning the protection ratios required to reduce the audible effects of co-channel interference to an acceptable limit. The results indicate that a satisfactory service (better than CCIR impairment grade 3) would be obtained in any part of the service areas of a network covering Western Europe and operating with a 6% duty factor. A subjective advantage is found when the interference is composed of a multiplicity of speech-modulated transmissions, and this tends to offset the increased overall interference level when such conditions prevail at night-time due to sky-wave propagation.

The f.m. coded START or FINISH signals, when radiated by an interfering station during a wanted message, are found particularly irritating if only one interfering signal is dominant, and in this case a protection ratio of 28 dB is required for grade 3 impairment. However, in the more practical case in which the transmission carrying a START or FINISH signal is only one of eighteen interfering transmissions, the subjective effect is no worse than if no interfering START or FINISH signals were heard.

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APPENDIX

Abridged experimental transmission specification for "CARFAX"

(a) All transmitters will radiate on a common carrier frequency.

(b) When a transmitter is radiating a message, it is described as a message transmitter and the field-strength within its service area will generally be in excess of 1 mV/m.

(c)

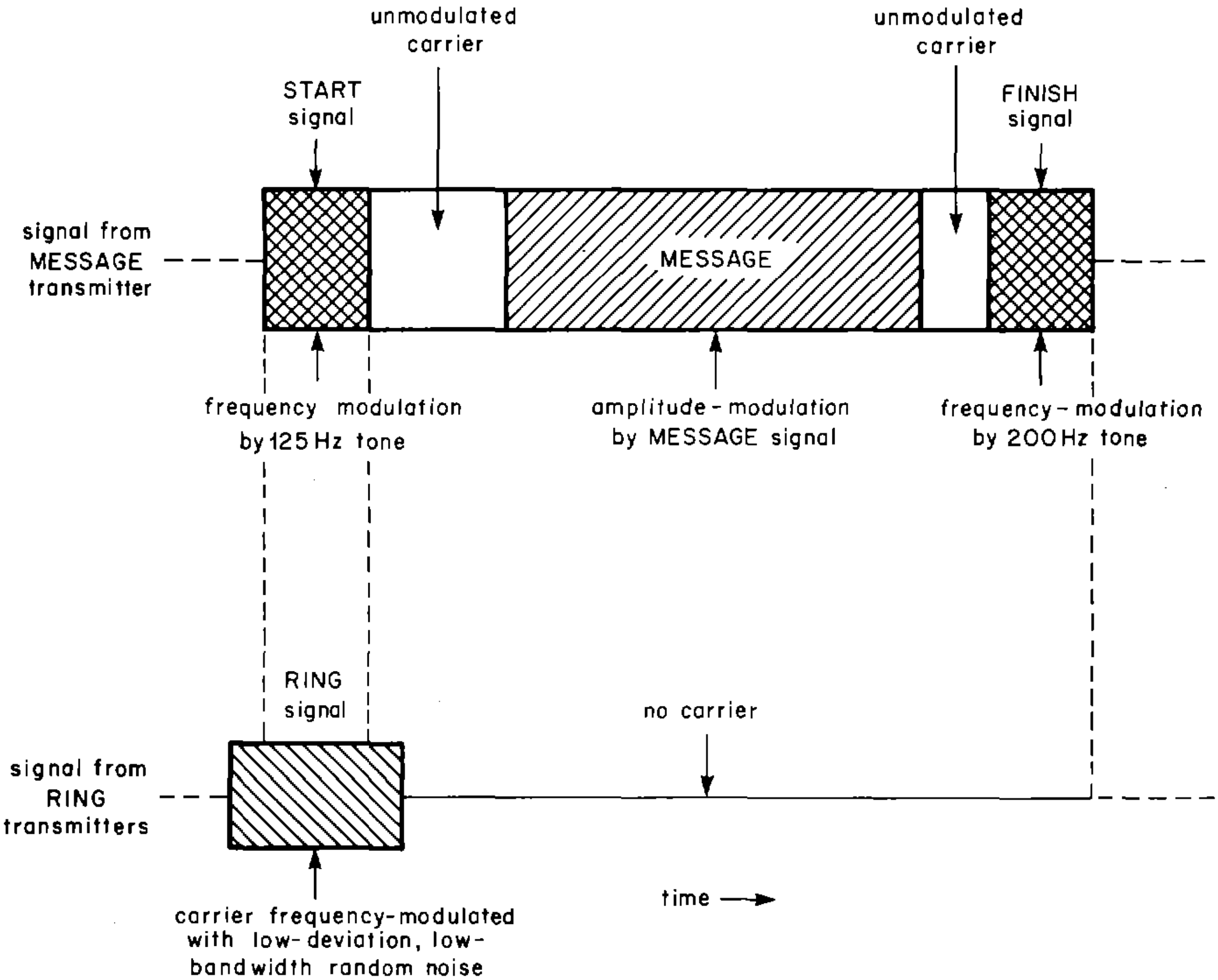

Fig. 15 - Message transmission format

Note that there is a START signal, a MESSAGE and a FINISH signal with periods of unmodulated carrier in between. Note also that a RING signal is radiated by other transmitters for a period which straddles the START signal.

(d) The transmitters surrounding the message transmitter are used to radiate the RING signals; in this role they are described as ring transmitters.

(e) The START signal consists of a 0.8 s burst of tone at 125 Hz, frequency-modulating the carrier to a peak deviation of ± 2 kHz.

(f) The period of unmodulated carrier between the end of the START signal and the beginning of the MESSAGE will have a minimum duration of one second, to allow receivers time to become activated.

(g) The MESSAGE will consist of spoken bulletins, possibly preceded and terminated by some call sign or 'jingle'. The MESSAGE signal will be pre-emphasised with a time-constant of 150 μs, compressed by about 12 dB, and will amplitude-modulate the carrier to a maximum depth of 95%.

(h) There may be a short period of unmodulated carrier between the end of the MESSAGE and the beginning of the FINISH signal, which are not intended to overlap.

(i) The FINISH signal will consist of a 0.8 s burst of tone at 200 Hz which will frequency-modulate the carrier to a peak deviation of $\pm$ 2 kHz.

(j) The RING signals will commence slightly before and end slightly after the START signal from the nearest message transmitter. The ring transmitters will remain off, once the RING signal has ended, for the rest of the sequence. The RING signal will consist of random noise, band-limited to about 100 Hz, which frequency modulates the carrier with a r.m.s. deviation of about 400 Hz. During radiation of the RING signal, transmitters may operate at reduced power relative to their role as a message transmitter.

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